Visual Representation in GENESIS as a tool for Physical Modeling, Sound Synthesis and Musical Composition

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ABSTRACT
The motivation of this paper is to highlight the importance of visual representations for artists when modeling and simulating mass-interaction physical networks in the context of sound synthesis and musical composition.

GENESIS is a musician-oriented software environment for sound synthesis and musical composition. However, despite this orientation, a substantial amount of effort has been put into building a rich variety of tools based on static or dynamic visual representations of models and of abstractions of their properties. After a quick survey of these tools, we will illustrate the significant role they play in the creative process involved when going from a musical idea and exploration to the production of a complete musical piece. To that aim, our analysis will rely on the work and practice of several artists having used GENESIS in various ways.

Author Keywords
Mass-interaction networks, sound synthesis, visual representation, artistic creation.

ACM Classification
H.5.5 [Information Interfaces and Presentation] Sound and Music Computing --- Methodologies and techniques.
H.5.2 [Information Interfaces and Presentation] User Interfaces --- Graphical user interfaces (GUI).
I.3.5 [Computer Graphics] Computational Geometry and Object Modeling --- Physically based modeling.

1. INTRODUCTION
Physical modeling for sound synthesis still is, more than 30 years after it emerged, a very active field of research. Additionally, more and more interested artists and composers are able to access a substantial amount of tools that integrate or completely rely on physical simulation, and all the main approaches have proved their relevance in musical creation [1]. In the literature, we can find several studies comparing these approaches, regarding very pragmatic and quantitative aspects, however one point is rarely considered despite its central role: the functional and ergonomic design of these tools in order for artists to easily apprehend them, understand the principles they rely on, and eventually be able to deeply integrate them as creation tools.

Since physical simulation consists, regardless of the employed modeling technique, in computing the evolution of a dynamical system, the questions at stake while modeling are by nature less "easy" to handle than those tackled with signal-based sound synthesis approaches. Consequently, we strongly believe that abstraction, representation, visualization and interaction are crucial in terms of usability of these techniques and tools. Nevertheless, very few of them come with dedicated graphical user interfaces (GUI) and even less with abstract models' visualization.

In its early development, the digital waveguides approach had its own dedicated graphical environment for prototyping instruments [2]. Nowadays, the latter are built directly in C++ or using more specialized programming languages such as FAUST [3]. Then, they can be included as toolkits in several environments (Max/MSP, PureData, CSound, SuperCollider, etc.). Despite some attempts e.g. [4], this approach does not allow a direct, comprehensive and coherent representation of models. Regarding digital waveguide meshes, several approaches of visual and interactive interfaces exist for specific cases e.g. [5, 6]. In the latter article, back in 1996, the authors envisioned that "3D digital waveguide structures will be a fundamental unit in a virtual environment of the near future in which anyone […] will be able to construct, analyze, and interact in real-time with complex physical models in both visual and acoustic domains". However, nowadays nothing seems to cover, even partially, that description.

PMPD, PMSC, MSD, STK are toolkits implementing several physical modeling approaches. Some of them allow the user to take advantage of the modularity of the environments in which they are included (mainly PureData, Max/MSP, SuperCollider) to build his/her own models. Sometimes, it is possible to obtain a static or dynamic visual representation of the models by using third party tools, such as GEM [7]. BlockCompiler [8] requires coding models in LISP and eventually making them available in MATLAB. The Modalys framework [9] originally allowed creating models by using C++ or Lisp coding; models can then be integrated into Max/MSP or MATLAB. Modalys-ER, a dedicated but limited interface aimed at Modalys model construction, has been developed and also ported into OpenMusic under the name of MfOM [10]. Cymatic [11] has its own user interface and allows to build models and to visualize their motion. A GUI for building models has been prototyped for Synth-a-Modeler [12] and might still be in development.

Finite Element, Difference or Volume Methods, allow very high quality rendering of models dynamics, but there is no dedicated environment to build and experiment them so far, and one has to revert to C++ or MATLAB to write models.

With this paper, we aim to illustrate what the functionalities provided by the GENESIS environment are, how users take advantage of them, and by extension, how users might need these kinds of tools to really make use of physical modeling.

2. CORDIS-ANIMA Networks

CORDIS-ANIMA [13] is a modular language that provides a set of primitive elements, modules that satisfy Newtonian physics. Modules fall into two categories: the <MAT> modules that designate “matter”, being either moving or fixed, and the <LIA> modules that designate interactions and allow interconnections between <MAT> modules. Each module has its own set of parameters and will process and exchange two kinds of variables through time: positions and forces.

3. Visual Tools in GENESIS

In GENESIS, physical networks are built, observed, analyzed, edited, understood mainly through graphical representation. There are three main workspaces in which the models and their properties have specific and complementary representations.
More details about the following description of functionality and GUI of some the GENESIS environment tools can be found in [14, 15, 16].

3.1.1 The Bench

The bench is a 2D space in which artists are able to construct, to model, physical networks by direct manipulation. Indeed, the basic CORDIS-ANIMA modules are graphically represented as colored disks in the case of <MAT> modules and colored lines in the case of <LIA>. An unlimited number of these modules can be dropped onto the bench and connected to each other, by direct manipulation. It is important to note that the two dimensions of the bench have no impact on the behavior of a model when it is simulated. The model will only move in the one direction perpendicular to the bench and its properties will only depend on its modules’ parameters and interconnections.

The bench represents a square of 200x200m, which is zoomable continuously to a 0.1mm scale. The networks “density” is not limited and can go far bellow this minimal scale. The GUI construction, by its navigation modes and tools for selection, global or local manipulation and edition, allows easily building complex and large models (up to millions of modules). It is also possible to add notes directly on the bench. (A bench note is a textual item encoded in HTML, including hyperlinks).

3.1.2 The Simulation Window

The first purpose of the simulation window of GENESIS is to obtain a sound out of a simulated model. But, in its specifications, this tool is paradoxically far more graphically oriented. Indeed, in addition to computing the simulated sound, displaying its waveform and allowing exporting it as an .AIFF file, the most part of the simulation windows is dedicated to graphically animate the model into a 3D workspace (2 dimensions being the ones of the bench and one dimension being dedicated to the models movements). The representation of the movement axis allows to continuously zoom from $10e^{-30}$m to $10e^{30}$m.

This 3D rendering comes along with numerous navigation tools and camera settings. The model can be played synchronously with the synthesized sound, or can be seen independently. In such case, the animation can be calculated at 44100 frame/sec and the time stretched down to display one frame by second.

3.1.3 The Modal Analysis Window

This workspace allows the decomposition and display of specific “acoustical” properties of any linear physical networks built on the GENESIS bench (up to 9000 modules). It is composed of three different parts: 1) A synthetic sheet, gathering the whole information relative to each identified vibration mode of the structure (frequency, equivalent note, octave, cents, and damping time). 2) A modal shapes visualization, individually displaying an interactive and animated 3D representation of each modal shape of the physical network. 3) A normalized impulse response graph, displaying the relative amplitude of each vibration mode given a couple of excitation and listening points.

4. USAGES

In the following, we will refer to and illustrate either general possibilities offered by the previously mentioned tools, or more specific experiences and practices of several GENESIS artists.[1] Each one of the following examples is fully developed in the video that you will find at the following address:

https://www.youtube.com/watch?v=ygLZIacH5LY

4.1 Create and Understand

The workspaces presented previously are three independent windows of the same software environment. The bench is of central importance since it is the space around which the modeling activity is organized. The simulation and modal analysis workspaces are launched from the bench window relatively to its content, which will be either simulated or analyzed. The most generally observed and encouraged behavior of GENESIS users is to permanently switch between these workspaces to take advantage of their complementarity. In the following section we will see how this back-and-forth support users in their creation, and the preeminent role played by the visual representations offered in these workspaces.

4.1.1 Observe and Understand

4.1.1.1 From elementary to large models

Once one has built a model and set its parameters onto the bench, the simulation can be launched in one click and a new window pops up. By accessing this new workspace, the user will be able to hear the synthesized sound. And since this sound is the direct result of the model’s movement through time, this movement will be visualized as well e.g. Figure 1 and Figure 2.

At this stage, users can already establish perceptive connections between the model they built, all its parameters, and the nature of both the sound and the movement it produces when simulated.

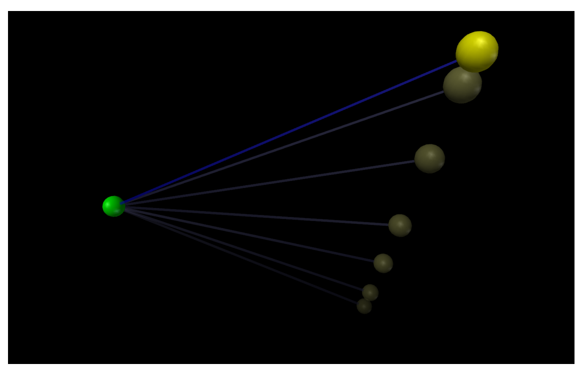

Figure 1. Simulation Workspace: Basic Oscillator.

[1] Since the first release in 1996, we evaluate that close to 100 musical pieces have been created with GENESIS. Importantly, all the corresponding physics-based models have x been designed by the artist himself.

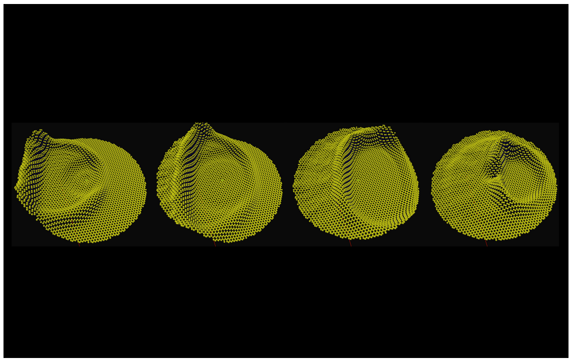

Figure 2. Simulation Workspace: Propagation through a 12000 modules plate.

4.1.1.2 Non-linear models

When it comes to non-linearity, graphic representation is of primary importance. Firstly, so the user can set them up. The bench actually includes a dedicated interface for both non-linear viscosities and stiffness (see Figure 3). Secondly, so the user can observe the effect of non-linear interactions between or in within models as shown in (see Figure 4), representing a model of a bowed string and the resulting Helmoltz movement. One can also observe the rebounds of strikers hitting any kind of model, or a plectra pulling then releasing a string, etc.

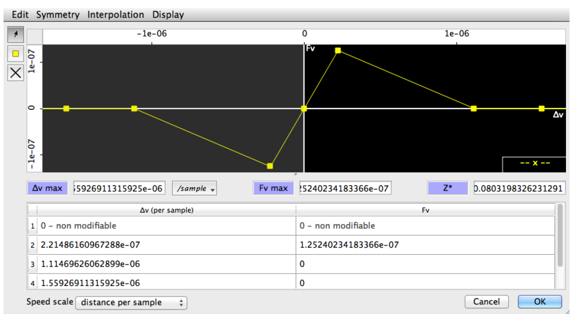

Figure 3. Complementary graphic interface for non-linear viscosity setting on the bench.

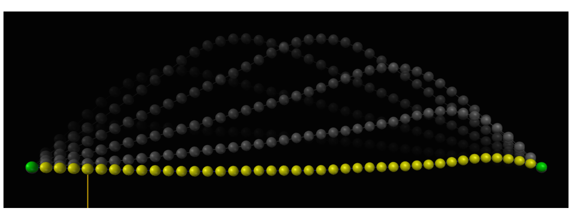

Figure 4. Simulation Workspace: Helmholtz Movement on a string model, by JL.

4.1.1.3 Through time and space

Physical networks can be classified in two categories. On one side, they can be "instrumentists" when their movement is at a low frequency. This supposes that these models will not produce any sound by themselves but will be used as gestural generators. On the other side, if they move at high frequency, they will be "instruments" and will be able to produce sound. A fundamental aspect of using GENESIS for musical composition, that we will come back to in section 4.2, is precisely to combine these two kinds of models and make them interact. Therefore, in order to observe the movement of these parts in the same simulation space, one will be able to play the model animation independently from the sound and to slow it from 44100 frame/sec down to 1 frame/sec.

Likewise, the movement of instrumentist and instrument models can occur at various spatial scales. One could easily observe movements, in the same space of simulation and with a continuous zoom, from the scale of quarks to the scale of the distance between our galaxy and the one of Andromeda. This consideration was the very purpose of Claude Cadoz's piece "Pico…TERA" [17].

4.1.2 Measure and Adapt

All the above observations can be a way for users to validate or reject and then adapt their models and settings. Of course, the sound is a central criterion but since in most cases it is obtained by listening to local parts of a model, being able to visualize the latter and its movement as a whole leads to very different and relevant information.

This is especially true in the case of non-linear models or for any kind of model going wrong when simulated. At some point in their exploration, artists can be confronted with tricky phenomena such as instable or divergent behavior. They can also try to get out of the safe range of parameters settings, for instance by including negative values of stiffness or damping, which is fine and will lead to very interesting sounds, but might be extremely sensitive and needs to be accurately controlled. In these cases, sound will not help that much, its amplitude could grow exponentially or the way of capturing sound could be in itself inappropriate. The visualization can be the only reliable modality to monitor what happens and adapt if necessary.

More generally adopting a recurrent cycle between the modeling workspace (the bench) and the simulation workspace, the user can: 1) Understand and build a knowledge on models and their properties and the incidence on both the synthesized sound and visualization. 2) Having this knowledge, and thanks to the two complementary modalities of hearing and seeing proposed in the simulation workspace, be able to connect what they perceive directly to properties a model has or should have.

Having a visual representation of the virtual environment in which physical models are simulated allows quantitative observations as well. In that case, and only by using the elementary CORDIS-ANIMA modules, one can build metrological models and "empirically" experiment and measure properties of dynamic structures directly into the simulation workspace. The simplest case, since we evocated scales above, would be to arrange a certain amount of static <MAT> modules at different heights, metaphor of a ruler, along the movement axis. This can be useful when the user needs an accurate control over the amplitudes of his/her model. It is also possible to build peak detectors, or even resonator-bank frequency analyzers. The latter can be a relevant substitution to modal analysis when applied to non-linear vibrating structures.

4.1.3 Modal properties of physical networks

A way to ease the connection that one will be able to establish between a linear model and the variety of sounds that will come out of its simulation is to project this model in another workspace, the modal analysis. Here, the user will know every detail of the vibration modes of the structure, observe their shape, and can therefore anticipate, without simulation, the main features of the sound this object will produce (see Figure 5). All this allows for example to clearly identify nodes and antinodes of the vibrating structure, and ultimately determine where to act on a structure in accordance to modes/partials that should or should not be predominant.

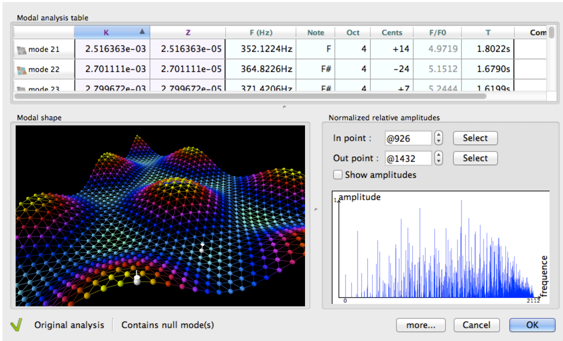

Figure 5. Modal Analysis Workspace

It is important to point out that the panoply of tools mentioned so far is a solid basis for didactic applications, and that GENESIS is used in University Institute of Technology of Nantes, Montpellier and Grenoble to introduce acoustics fundamentals.

4.2 Explore and Compose

In this part we will present how users are able to explore, to document their explorations, and to compose with physical networks, especially in the bench workspace. Indeed, the bench is thought of as a blank page on which the position of objects doesn't matter at all in the resulting sound. The artists are then free to use it for multiple purposes.

4.2.1 Structuration of the exploration

An environment made for creative purpose has to ease the way users will keep track of their explorations in using them. In the case of GENESIS, the bench allows to visually store and access all the steps of a specific creation process.

There is no limitation in terms of modules it can support, and a simulation can be launched for only a selection of these modules. Therefore, the bench enables to build corpuses of objects revolving around a central modeling or musical concept, offering a way to preserve milestones of musical exploration, while operating slight structural or parametric modifications over an original model. Furthermore, one can write notes containing any kind of HTML text directly on the bench and document various aspects of models, parameters explorations, etc. The following figures illustrate the documentation of various experiments (see Figure 6, 7 and 8).

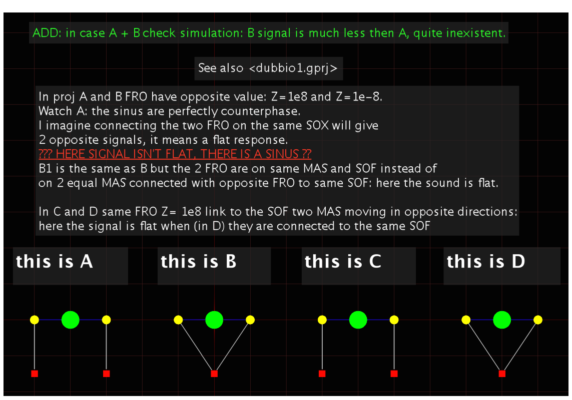

Figure 6. Bench Workspace: "dubbio_2" by GG Exploration of listening methods in GENESIS.

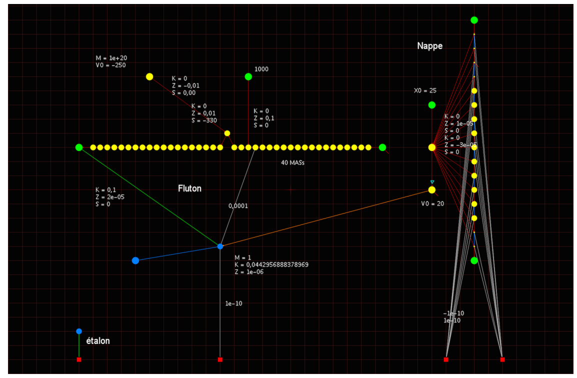

Figure 7. Bench Workspace: "Fluton" by CC Direct visualization of the model parameters.

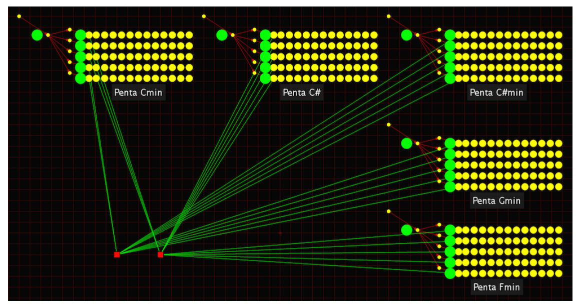

Figure 8. Bench Workspace: "Albizia" by JV Corpus of different tunings of a same structural model.

4.2.2 Orchestration

The artists can also gather a collection of very different models directly onto the bench, and versions of these that work well together (see Figure 9). It is up to him to organize and position them, to categorize them functionally or even relatively to aesthetical exigencies. We can also mention the possibility to think here about their projected spatiality in the resulting sound. GENESIS does not set any limit in terms of number of audio channels composing the synthesized sound. Therefore, one can find useful to segment the bench in a way to represent what the spatialization of the sound will be when played on multi-channel installations.

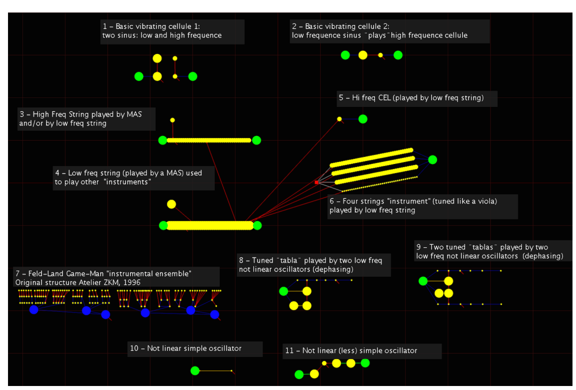

Figure 9. Bench Workspace: "Bench14" by GG

4.2.3 Composition
Due the wide space and liberty in positioning and organizing models on the bench, the use of GENESIS can be pushed a littler further and allow one to compose with models and to build complete musical pieces. This does however suppose strategies and tools to arrange them in time, and somehow to elaborate a musical notation on the bench itself.

4.2.3.1 Writing events on the Bench
We first depicted two categories of models, the "instruments" and the "instrumentists". There is a third one, quite elementary, which role is to trig different parts of a model at a certain moment. Mostly, these models, these "triggers", it can be one for each imagined event, are built out of only one mass module and are connected to "instruments" by the mean of non-linear interactions. By setting them with precise initial speed and position in space, the composer can decide at which time the "instrument" part of a model will be excited and will actually play its related "instrument". The most direct strategy to organize these triggers, once they are properly set, is to map their temporality to an abstract scale directly on the bench.

To illustrate that, the above figure (see Figure 10) represents a small part of an 8 minutes long piece. On the bottom (below the two white lines), are placed several groups of instruments/instrumentists, on the top, are aligned several triggers, identified by marks on above them. This horizontal organization is precisely readable as a sequence of events, a score, written by the artist. Here, the triggers will play the different groups, and sometimes a group will be played multiple times, in a left to right execution with a two minutes range between the first trigger and the last one.

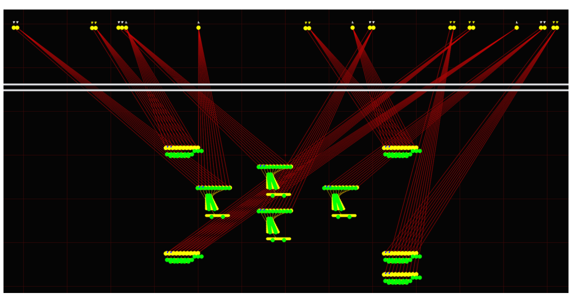

Figure 10. Time Notation in "Gaea" by CC.

4.2.3.2 Organizing events in the Sequence Editor
Users can also choose to organize events with another approach that the one previously mentioned. Triggers can be displayed and edited in a dedicated window, a dedicated Sequencer (see Figure 11). Once identified as triggers on the bench, they will appear on timelines. Dragging triggers along them will automatically modify their initial conditions and of course the sequence of musical events.

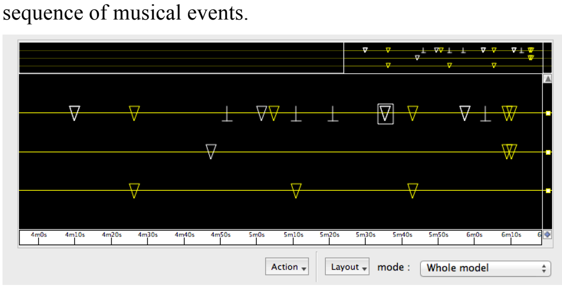

Figure 11. Sequence Editor Window: A sequence of "Gaea"

It is important to note that moving the representation of a trigger in the sequence editor will not move the referred trigger on the bench. In a way, it is up to the artist to choose between the bench and the sequence editor as a reference for his/her composition.

4.2.3.3 From one to another
Some other tools exist to help user regarding the previous remark. Thus, it is possible to go from one reference to another. GENESIS includes a script language dedicated to mass-interaction networks modeling. This tool is fully integrated to the environment and can be a good complement to the direct manipulation allowed when working on the bench. For instance, in our case, it is possible by using scripts to interpret relative positions of triggers on the bench in a way to automatically set these their initial conditions. Conversely, it is possible to automatically interpret initial conditions of triggers and align them properly on the bench like in (see Figure 10).

4.2.3.4 Visualize events in the Simulator
The triggers introduce new space and time scales for users to apprehend within the simulation workspace. These elements can be very slow objects, and only be effective seconds, minutes or more after the beginning of a piece. Plus, their initial positions can be extremely far from the objects they will act on. This implies slower movements and a wider spatial disposition. Hence, it also opens to a new interpretation of the visual feedback during the simulation: as an auto-scrolled score, or as illustrated bellow (see Figure 12) as a punched card, unfolding through time, connecting each event occurring in the musical piece to a visual cause.

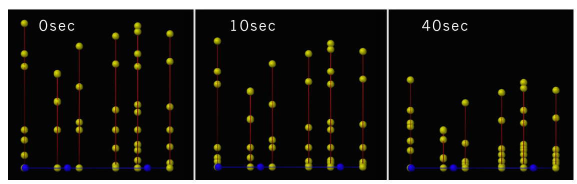

Figure 12. Simulation Workspace: "MusicBox" by GG.

The previous figure illustrates the progress of a two minute long piece in the simulation workspace. Three steps at different times are represented. Each yellow dot is a trigger continuously "falling" from the beginning of the simulation to the moment they hit an instrument, which produces a sound. Afterwards, they will go back in the inverse direction and will not interact again until the end of the simulation.

4.3 Aesthetical Approach
Finally, we will refer to uses of GENESIS that go beyond sound synthesis and musical composition in itself.

4.3.1 Tablature
The bench is a well-suited support for writing instruments, instrumentists and music. And, in the end, when the piece is complete and can be heard, there is this part of it that might be of great interest. A pictorial piece in itself illustrating either the very methodology of the artists when composing it, or a pure aesthetical arrangement and construction of objects, not even necessarily meant to evocate the music that they have been used to produce.

That was the point of the first exposition of its kind during #AST 2011 in Grenoble (see Figure 12), where 10 "Hyper-Tablatures" where presented, without any sound, only to be seen, inviting people to get closer and imagine what sound might come of them.

Figure 13. #AST 2011 Exposition: Tablature by CC;

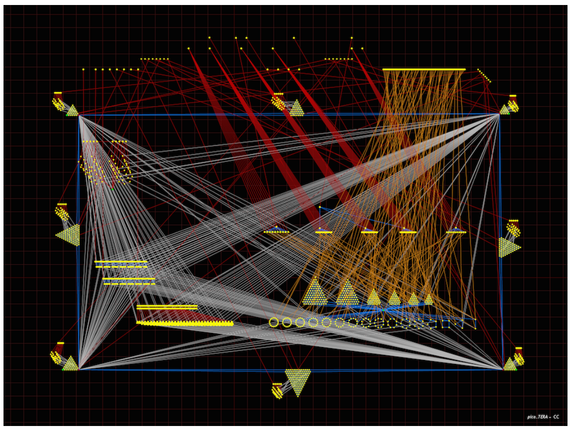

Figure 14. #AST 2011 Exposition: Tablature by CC – pico..TERA.

4.3.2 GENESIS as a tool for AudioVisual Creation.

For its part, the simulation workspace can be seen as a complete audio-visual synthesis environment, and maybe the first of its kind. In its core, one unique physical model is responsible for an intricately linked audio and visual-motion production without any reference to any kind of mapping between these modalities. It implies that when using GENESIS, the artists can focus essentially on sound but might consider what will be seen in the simulation workspace as an object of its creation as well.

Ludger Brümmer and Silke Braemer in "Le temps s'ouvre" (Thrill), used GENESIS in its earliest public version as a multimodal tool producing both sound and animated images used as raw material for post-treated video creation. More recently, Claude Cadoz has been publicly playing his piece Gaea and other compositions directly from the simulation workspace and simultaneously navigating in the model visualization. The audience is then guided in an immersive journey across the different scales and parts of the model while listening to it.

It is interesting to note that we are here moving slightly away from the notion of acousmatic music since the audience can actually see a coherent representation of the instruments with which the sounds are produced.

5. CONCLUSION

The GENESIS environment is dedicated to sound synthesis and musical composition by means of physical networks modeling. But for users to acutely experience it, whatever their scientific background may be, from basic sounds to the elaboration of complete pieces, it has been conceived as a coherent and rich ecosystem where the model and its representation and visualization are always a central preoccupation. As a consequence, and by considering the actual ways in which artists use it, we can observe that GENESIS is a little bit more than just a sound synthesis and musical composition environment.

6. ACKNOWLEDGMENTS

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